

Mercury Free Microscopy: An Opportunity for Core Facility Directors

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Mercury Free Microscopy (MFM) is a new movement that encourages microscope owners to choose modern mercury free light sources to replace more traditional mercury based arc lamps. Microscope performance is enhanced with new solid state technologies because they offer a more stable light intensity output and have a more uniform light output across the visible spectrum. Solid state sources not only eliminate mercury but also eliminate the cost of consumable bulbs (lifetime ~200 hours), use less energy, reduce the instrument down time when bulbs fail and reduce the staff time required to replace and align bulbs. With lifetimes on the order of tens of thousands of hours, solid state replacements can pay for themselves over their lifetime with the omission of consumable, staff (no need to replace and align bulbs) and energy costs. Solid state sources are also sustainable and comply with institutional and government body mandates to reduce energy consumption, carbon footprints and hazardous waste. MFM can be used as a mechanism to access institutional financial resources for sustainable technology through a variety of stakeholders to defray the cost to microscope owners for the initial purchase of solid state sources or the replacement cost of mercury based sources. Core facility managers can take a lead in this area as “green” ambassadors for their institution by championing a local MFM program that will save their institution money and energy and eliminate mercury from the waste stream. Managers can leverage MFM to increase the visibility of their facility, their impact within the institution, and as a vital educational resource for scientific and administrative consultation.

KEY WORDS: fluorescence imaging, light engines, funding opportunities, light source

INTRODUCTION

Fluorescence microscopy is a pervasive tool found throughout the physical, life, and health science disciplines. Hundreds of microscopes can be found in most research institutes, hospitals, universities, and biotech and pharmaceutical companies. The majority of these instruments use mercury vapor arc lamps as an illumination source (HBO or metal halide). Recent advances in lighting technologies have now made it possible to replace these mercury-containing light sources with solid-state lighting options that have a much smaller environmental impact. Solid-state light-emitting diode (LED)-based light sources have been used in the laboratory for some time.^{1–4} However, advancements in solid-state “light engine” technology now provide laboratories with mercury alternatives that are straightforward to operate; environmentally friendly; affordable to buy; and more well-suited for bioimaging.^{5–9} Previous generations of LED technologies were typically based on a combination of multiple-colored LEDs that often missed key wave-

lengths in the visible spectrum. Key advancements have been the development of brighter solid-state illumination sources and true “white light” solutions (Fig. 1). Replacing existing mercury light sources with light engines will reduce operational costs and energy requirements, eliminate a major environmental hazard, and improve the viability and reproducibility of experiments. The return on investment for exchanging heavily used mercury-based sources with light engines can be satisfied in a relatively short period of time, yet whereas most laboratories covet the new technology, they find the initial cost prohibitive.

Mercury Free Microscopy (MFM) is an awareness campaign developed through a collaboration between the McGill University Advanced BioImaging Facility (ABIF) and Lumencor Inc., which provides education about the benefits of modern mercury-free lighting and encourages additional stakeholders at universities, hospitals, institutes, and companies to help defray the cost of these sustainable technologies. MFM will eliminate the environmental impact of large amounts of mercury (~110 mg/bulb), significantly reduce energy consumption and increase financial savings while providing a more uniform and stable light output (i.e., superior quality scientific data). Core facility directors are the ideal champions for an institutional MFM

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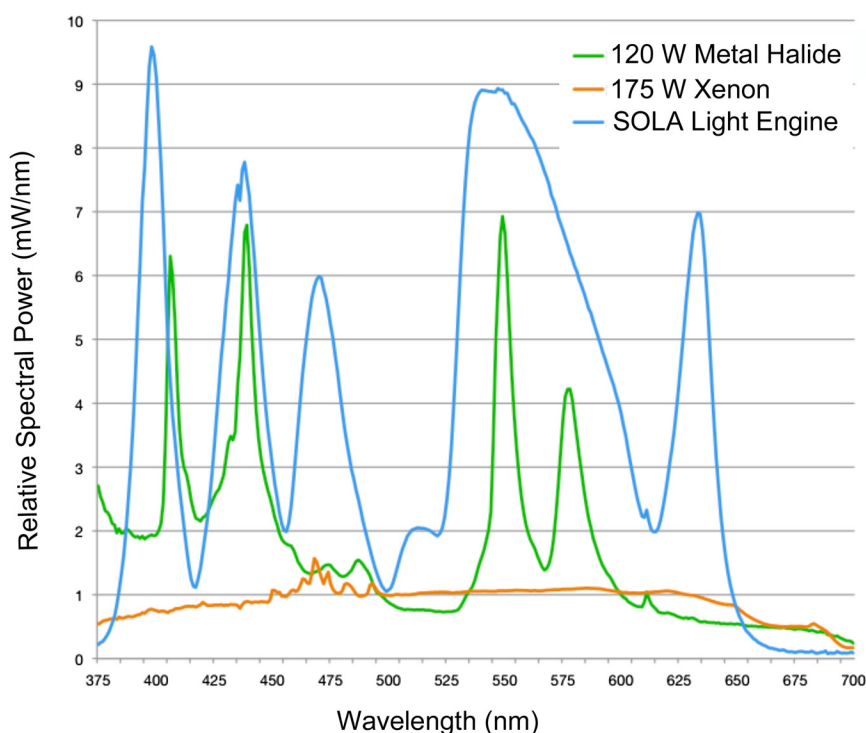


FIGURE 1

Relative spectral output of a traditional xenon lamp, a mercury-based metal halide lamp, and a solid-state SOLA light engine.

program, potentially using it to: (1) modernize existing equipment; (2) increase the visibility of the facility; (3) explore alternative funding sources from institutional programs; (4) become a leader in green laboratory programs; (5) consolidate an institutional instrumentation network; (6) centralize core facility equipment administration; and (7) be an increasingly impactful resource for experimental design, cooperative equipment funding, and sustainability awareness.

WHAT IS THE MFM MOVEMENT?

The MFM movement began when the ABIF at McGill University and Lumencor obtained funding from the McGill Office of Sustainability, through their Sustainability Projects Fund, to replace mercury-based light sources with “green” light engines. Ten mercury light sources in three imaging core facilities at McGill [ABIF, Cell Imaging and Analysis Network (CIAN), and the Montreal Neurological Institute microscopy core] were replaced with 75% of the funding coming from the Sustainability Projects Fund and the remaining 25% from the three core facilities. At the time, there was little information available directly comparing different light-source technologies so undergraduate students and ABIF staff members began rigorous testing of light sources as part of the education and community-outreach components of the project. The most

impressive aspect of light engine technology is that it is significantly more stable than mercury-based light sources on all time scales tested, with an increase of four to 20 times in stability (Table 1). This stability will generate more representative fluorescence images over time (time-lapse imaging) or space [three-dimensional (3D) imaging]. Data will be of higher quality, resulting in more precise quantitative imaging studies. Warm-up times from a cold start were two times faster with light engines, and the ability to shutter the lamp electronically with $\sim 5\%$ variability over the initial 5 min is an additional advantage. Stand-by mode resulted in a 50-fold or more reduction in power consumption versus mercury lamps (Table 1).

As a result of their solid-state nature, light engines can be shuttered electronically (no physical shutter is required), whereas mercury arc lamps need to be turned on and left on during long-term experiments. On confocal microscopes, light sources are typically only used for short periods of time to visualize samples. In this case, light engines can be turned off during long time-lapse or 3D confocal imaging experiments and readily turned on when necessary for sample observation. For wide field-type applications, light engines can be shuttered on and off electronically (or left in stand-by mode). Therefore, they only consume small amounts of electricity over the course of long experiments.

TABLE 1

Light Engine Versus Mercury-Based Sources¹

Parameter	Light engine	Mercury HBO lamp
Time Scale	Intensity variability	Intensity variability
300 h	2%	10%
200 s (every s)	<0.1%	2%
30 s (every 100 ms)	<0.1%	2%
100 min (every 2 min)	0.5%	2%
Test	Time for stabilization	Time for stabilization
Warm-up time (90 min)	20 min	40 min
Stand-by mode	5 min	NA
Power consumption	100–150 W, 100% intensity 2.0–2.5 W, stand-by mode <0.5 W, off	135 W, 100% intensity NA, stand-by mode 0 W, off

The 5% change in intensity when shuttering the light engine is very reproducible and should not cause a significant problem when using electronic shuttering and looking at samples over the long-term. Thus, significant energy cost savings can be realized. Next-generation light engines will have advanced thermal properties and should have even shorter warm-up and stabilization times.

Aside from improved light output stability, faster warm-up times, and reduced power consumption, there are several other benefits to the new Light Engines.^{9–10} There is no longer mercury waste that needs to be cleaned up and instrument down-time; staff time to change mercury bulbs and perform sometimes lengthy alignment protocols is eliminated; and the cost of replacing mercury bulbs (\$100–\$300) every 200–300 h is eliminated. In fact, for an initial purchase, the light engine results in >\$18,000 of savings over its 20,000 hour lifetime, relative to the cost of using a mercury-based light source for the same period of time. When these values are extrapolated for instruments institution-wide, the savings can be measured in kilograms of mercury, millions of dollars, and mega-Watts of energy.

The McGill Sustainability Projects Fund proposal also includes requirements of education, community engagement, and outreach. First, the MFM program will influence a shift in business as usual at the university toward the goals of sustainability. The ABIF is working with the granting office (Office of Sponsored Research) and procurement services to develop an educational document that identifies mercury-based light-source purchases and a mechanism to contact and educate researchers suggesting sustainable alternatives and the benefits of MFM. Second, the larger institutional community is engaged through MFM posters; training at the ABIF, CIAN, and Neuro microscopy core facilities; and information sessions. Third, undergraduate students and several ABIF staff have been involved in the

scientific testing of the light engines and the development of advertising and marketing material for MFM (Fig. 2). The ABIF is continuing to test the array of commercially available MFM light sources, generating scientific information, providing ideal projects for budding undergraduate scientists, and collecting information to make fluorescence microscopy more green. Phase 2 of the MFM project will aim to take the lessons of sustainability, cost savings, and scientific merit, measured during Phase 1, to educate scientists across campus about the benefits of MFM and to identify additional stakeholders to defray the cost of technology upgrades for all microscopes institute-wide. As the MFM program grows, procurement and granting offices will take over the educational aspects of the program, relying on the core facility managers for scientific testing and consultation.

DISSEMINATION

The MFM sustainability initiative at McGill has acted as the seed, sparking several new MFM initiatives at other institutions. Core facility directors have engaged their respective institutions using a variety of mechanisms to re-

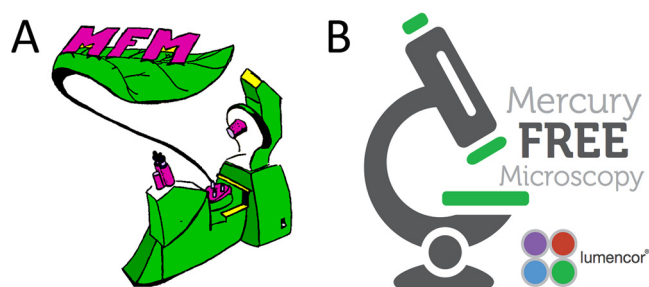


FIGURE 2

MFM logos. (A) This logo was designed by Daniel Kaufman at the ABIF. (B) This logo was designed by Lumencor.

duce or cover the initial investment costs for light engines. The Nikon Imaging Center at Harvard University received funding through a proposal to the Tools and Technology Awards Program from the Harvard Medical School Office of Tools and Technology. The Harvard Green Building Services is performing a life-cycle analysis, and Harvard Strategic Procurement is promoting light engines as a sustainable alternative for microscope lighting. Efforts are in place to host a MFM workshop at multiple campuses in 2014, to create a mercury arc lamp replacement fund.

The Harvard MFM initiative has been successful. “Like many microscopists, I’d been trying to get away from mercury based fluorescence illumination for many years. I tend to be conservative with changes to a microscope component as critical as the light source, and was finally convinced to make the leap to Light Engines [after prolonged testing]... I applied for and received internal funding from Harvard Medical School’s Office of Tools and Technology to upgrade 12 metal halide illuminators in my core facilities to Light Engines. I’ve been very happy with the ease of the transition. We measure the intensity of all of our fluorescence light sources weekly, and the stability of the Light Engines is remarkable. The obvious benefit of MFM to the environment is a bonus, but the real draw for me is the improvement in the precision of quantitation of fluorescence intensity that comes with stable light engine illumination.”

—Jennifer C. Waters, Ph.D., Microscopy Director, Department of Cell Biology, Harvard Medical School, Boston, Massachusetts, USA.

My Green Labs (MGL) was founded in 2013 to promote awareness and funding options for new, superior sustainable solutions for laboratories (at the institutional level), with a focus in California. One of its primary platforms is MFM, and it is working to identify available energy rebates and refunds associated with the transition to energy-efficient and sustainable light engines. The initial efforts of MGL are creating a synergy among sustainability officers, energy managers, safety officers, purchasing agents, and student groups that focus on environmentally sound solutions for laboratories. MGL is already finalizing an accredited “Green Labs” checklist that includes MFM and has brought MFM into the purchasing guidelines, written by International Institute for Sustainable Laboratories and the U.S. National Institutes of Health (NIH).

Additional institutions are in various stages of identifying alternative funding solutions for the transition to MFM. Proposals are in place, ranging from funds for single microscope upgrades to microscope upgrades across an entire state. (See Appendix for more quotations about MFM initiatives from microscopy experts.)

For the MFM program to continue to grow, stakeholders need to be informed. One key target group for successful and rapid dissemination of this information is core facility managers and directors. An information session on the program was featured at the Canadian Cytometry & Microscopy Association (www.cytometry.ca) symposium in June 2013 in Montreal, where more than 60 Canadian core facility personnel were in attendance. On a larger scale, a similar MFM information session will be held at the international core facility-centered meeting—Association of Biomolecular Resource Facilities (<http://conf.abrf.org/>)—in Albuquerque, NM, USA, on March 22–25, 2014.

HOW MFM BENEFITS INSTITUTIONS

Mercury is a highly toxic element. Only 1 g of mercury can contaminate a lake with a 25-acre surface area. Thus most major institutions have an ongoing mandate to eliminate mercury waste. Research and medical laboratories tend to have special exemptions, as some mercury-containing products are considered vital for scientific research. For example, the NIH has a mercury-free mandate but provides an exemption for mercury-based, scientific-grade lighting, as it is “essential in health care facilities”. Light engine technology has now been proven as a superior and sustainable alternative that renders this debate moot, especially for microscopes. To put the mercury levels in lighting in perspective, household compact fluorescent bulbs (CFLs) operate at ~5000 h/mg mercury, whereas scientific bulbs operate as few as 2.5 h/mg mercury. This effectively means that the amount of mercury contained in one mercury bulb is equivalent to the amount contained in ~2000 CFL bulbs. The environmental impact of removing just one single mercury-based light source from a microscope is indeed surprising. However, institutions can have hundreds or thousands of microscopes with mercury-based illuminators, so an institution-wide replacement with suitable light engines will have a huge environmental benefit by eliminating kilograms of mercury from the wastestream. Also, each replacement will eliminate ~\$18,000 in consumable cost per microscope, saving the institution and/or granting agencies millions of dollars.¹⁰

Light engines will also reduce energy consumption, in line with institutional mandates to reduce their carbon footprint. Mercury-based arc lamps require high-energy levels to ignite and must remain “on” over the entire duration of experiments, even when not in use, as frequent on and off cycles reduces bulb lifetime and the quality of illumination. Light engines typically operate at lower power (Table 1) and can be turned on/off frequently and almost instantly. This reduces energy consumption and results in a longer lifetime. For example, if an experiment required the lamp to be on for 1 s every hour for 3 days, the

arc lamp would be consuming energy for 72 h (~23 pounds of CO₂), whereas the computer-controlled light engine would be energy-consumptive for only 72 s (0.0002 pounds of CO₂).¹⁰ This is a 3600-fold reduction in energy consumption, potentially saving megawatts of energy if an institution replaces multiple mercury sources.

Unfortunately, many institutions have neither a strong inventory of their microscopy resources nor accounting of mercury arc lamps, which can easily lead to gaps and overlaps in equipment and functionality. Initiating centralized management of these resources by the resident microscopy expert, such as a core facility director, would increase use and efficiency of instruments, while preserving their flexibility. Centralized management will also ensure that equipment is optimally functional and handled appropriately, resulting in increased productivity. Also, future capital equipment requests and expenditures evaluated by the core facility manager as an authority on institution-wide and cross-disciplinary applications will maximize the return on investments in equipment and increase the likelihood for funding.

MFM is designed to connect institutional stakeholders, such as procurement, research grant, and sustainability offices, and student groups with the resident scientific experts in core facilities to provide a mutually beneficial collaboration. As a program, MFM can be championed by the core facility director to take inventory of the institutional resources; identify gaps and overlaps; and calculate energy, mercury, and financial savings for the institution, while being welcomed by each laboratory as a resource, providing superior, more sustainable, new technologies. There are many new green buildings with Leadership in Energy and Environmental Design status for state-of-the-art research and clinical laboratories, but these become populated with old, inefficient, nonsustainable equipment. MFM can serve as a gateway to facilitate responsible laboratory practices and purchasing discussions, beginning with mercury-based lighting. Core facilities can act as hubs of education resources for both the institutional offices and potential end-users. The testing of new equipment can also be a way to bring students and facility staff into the sustainable program, ensuring the scientific use of new technologies. A successful MFM program will create a financial partnership among many stakeholders in the institutions including: (1) individual laboratories or core facilities (budgets for consumables); (2) environmental health and safety and sustainability programs; (3) procurement units (with buying power); (4) energy rebate and incentive programs; and (5) private donations to defray the upfront cost of modernizing mercury-based technologies to sustainable light engines. MFM will be a program that promotes

institutional mandates for reducing mercury and energy consumption, boosts millions of dollars in savings, modernizes scientific equipment, and potentially streamlines administration of a major equipment resource.

MFM BENEFITS FOR THE CORE FACILITY MANAGER

The purchasing of a new light source that provides an appropriate amount of stable light intensity is paramount for accurate quantitative imaging. However, the replacement of an existing mercury-based light source with a light engine is significantly more expensive than a single, new bulb, so most laboratories continue the consumable cycle with mercury bulbs until they have far exceeded the cost of a light engine. The light engines improve scientific data that are collected; eliminate lamp failures, thus reducing the instrument down-time; save on staff time that is no longer required to install and align bulbs; and reduce operational costs, including electricity use and bulb purchases. With stakeholders and institutional funding to defray the cost of light engines through an MFM program, researchers can make a conscious green decision without financial hardship and maintain their environmentally aware lifestyle inside of the laboratory.

Core facility managers—resident experts in fluorescent microscopy, imaging techniques, and experimental design—are often required to provide partial or full funding of operational costs and instrument-support contracts through a variety of usage charges. Facilities also compete for usage time with similar instruments outside of their jurisdiction. In fact, most institutions have several duplicate (and expensive) microscopy systems that may be underused as a result of a lack of awareness, accounting, and administration. The core facility typically benefits as the first stakeholder in the MFM program with financial savings and improved equipment. In championing a MFM program, the core facility manager can increase his or her visibility by overseeing the inventory of all of the microscopy systems available on campus, calculating the metrics needed to validate a MFM proposal, and identifying the gaps and overlaps in technology across the institution. He or she will not only provide institutional imaging expertise but also could have a greater impact on the institution by centralizing administration of this large instrument inventory. As the central node in the instrument network, facility managers are then ideally suited to identify the cross-discipline collaborations required for strong capital-equipment grant applications. Their MFM outreach will also strengthen relationships with individual laboratories by providing introductions, cost-effective equipment solutions, and opportunities for consultation. The MFM champion will be a prominent figure in the institution's public relations, as a fulfillment of

mercury and energy reduction mandates through the MFM program is announced.

CONCLUSION

In just over 1 year, the MFM movement has gained significant traction at several high-caliber institutions (see Appendix), where conversion from mercury arc lamps to light engines has been shown to provide benefits scientifically, economically, and environmentally. The program is flexible, drawing from various governmental, corporate, and institutional programs for success. Programs have been typically biphasic, starting from a local pilot evaluation, followed by expansion throughout the institution. Successful programs have included student projects exploring the scientific and environmental merits of MFM, with community outreach and workshops targeting the scientific research and sustainability communities. MFM is an inclusive gateway for sustainability issues and solutions targeted toward the biomedical research community. Core facility managers have been paramount in expanding the MFM movement and may be able to find additional career benefits through championing a MFM program at their institution.

APPENDIX

“We are pursuing MFM to reduce our heavy metal contribution to the waste stream, simplifying operation of scopes and reducing our carbon foot-print through electrical consumption by 95%. This will also give us the opportunity to improve agency efficiency through the creation of an imaging user database that will allow for sharing and consolidation of resources. It will also improve the science being done by reducing phototoxicity and increasing fluorophore stability.”

—Richard Cole, director of the Advanced Light Microscopy and Image Analysis Core, New York State Department of Health, Wadsworth Center, Albany, New York, USA.

“We are currently working with Lumencor and Harvard’s Office for Sustainability to determine how this program [MFM] will take shape. To date we have been impressed with the technical specifications and performance of Light Engines. In addition, our preliminary analyses indicate that a conversion to solid state illumination will not only help us rid our facility of mercury containing bulbs, but also present a considerable financial savings by eliminating/reducing expensive bulb and liquid light guide replacements and electricity consumption.”

—Douglas Richardson, Ph.D., director of imaging, Center for Biological Imaging, Harvard University, Cambridge, Massachusetts, USA.

“I’ve decided to eliminate mercury based illumination

in microscopes within my core for a variety of reasons. Besides the obvious elimination of a highly toxic element, I find that the Light Engines perform better for my applications, especially when using green and far-red fluorophores. Additionally, a combination of energy efficiency, unit life, and solid state triggering to eliminate mechanical shutters made the decision to switch to Light Engines very simple.”

—Matt Kofron, Ph.D., assistant professor and director, Confocal Imaging Core, Children’s Hospital Medical Center, Division of Developmental Biology, Cincinnati, Ohio, USA.

“Since getting the seven source Light Engine on our Deltavision system we have had an increase in successful imaging. For fixed samples it is even and very fast; for live it is so controllable we have no trouble keeping the cells happy and alive. We would like to have this kind of mercury-free light source on all of our systems but find that our institution is not [currently] willing to support a more ecological approach with financial support or incentives.”

—Aurelie Snyder, imaging specialist, Advanced Light Microscopy Core @ The Jungers Center, Oregon Health and Science University, Portland, Oregon, USA.

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